Research Article

A Tele-Health Communication and Information System for Underserved Children in Rural Areas of Nicaragua

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Abstract

Millennium Development Goals point out the necessity of actively promoting maternal-child health care status, especially in underserved areas. This article details the development actions carried out between 2008 and 2011 in some rural communities of Nicaragua with the aim to provide a low-cost tele-health communication service. The service is managed by the health care center of Cusmapa, which leads the program and maintains a communication link between its health staff and the health brigades of 26 distant communities. Local agents can use the system to report urgent maternal-child health care episodes to be assessed through WiMAX-WiFi voice and data communications attended by two physicians and six nurses located at the health care center. The health and nutritional status of the maternal-child population can be monitored to prevent diseases, subnutrition, and deaths. The action approach assumes the fundamentals of appropriate technology and looks for community-based, sustainable, replicable, and scalable solutions to ensure future deployments according to the strategies of the United Nations.

1. Introduction

Governments all over the world should ensure the availability of health services, healthy and safe working conditions, adequate housing, and nutritious food. Article 24 of the UN Convention on the Rights of the Child states that "All children have the right to the highest attainable standard of health including access to primary health care, nutritious foods and clean drinking-water" (United Nations, 1989). These factors influence children's optimal growth and development. Access to fresh water and primary health care critically determines the quality of life of the maternal-child population. Developing countries especially need assistance because the population typically lives in remote areas with lack of access to basic health care such as prenatal monitoring, immunization, and growth and development control.

In the United Nations' *Human Development Report 2011,* it is pointed out that access to suitable and affordable health care is still a critical challenge (UNDP, 2011). The *Rural Poverty Report 2011* (International Fund for Agricultural Development, 2011) shows that children and young people comprise a large portion of the 1 billion hungry people who live in rural areas of developing regions. A severe and prolonged lack of food causes bodily deterioration, apathy, loss of social meaning, and indifference (Trueba, 2006). Inhabitants in areas subjected to poverty conditions are

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the first victims of malnutrition. The most vulnerable population groups are children, pregnant and breast-feeding women, people with disabilities, and the sick and the elderly. According to the World Health Organization (WHO), every year, more than 200 million children under age 5 fail to reach their full cognitive and social potential (WHO, 2007). As a result of poor development, young children are likely to have inadequate health care, nutrition, and stimulation. This fact contributes to the transmission of poverty and poor development between consecutive generations. The need to encourage and ensure development in early childhood and to support families with appropriate information and facilities is clear.

Therefore, the WHO focuses on the need of health care providers, managers, planners, technicians, and policy makers to use accurate information to support evidence-based decisions for timely health care delivery to underserved populations.

To help reach this goal, this article describes the analysis, design, implementation, deployment, and verification of a field experience to support rural communities in extreme poverty in Cusmapa, Nicaragua. An information and communication system is developed to strengthen tele-health-based follow-up on the health and nutrition status of the maternal-child population in remote and underserved communities.

This research project is part of a program titled "Millennium Rural Communities" supported by a grant from the Technical University of Madrid, Spain, in cooperation with other universities such as Universidad Nacional Agraria, Nicaragua. The research mission is to strengthen the capacity of rural populations through replicable, sustainable, scalable, and community-based projects to tackle the components that extend the cycle of hunger, poverty, and disease to achieve the MDGs. The target areas of the program are the Chortí communities in Jocotán, Guatemala, and the Chorotega region of Cusmapa, Nicaragua, which are territories of Central America with high rates of hunger, disease, and poverty.

The next section of this article describes related work that justifies the impact of emerging information and communications technologies (ICTs) in various health care projects in developing countries. Section three depicts the health system profile in Nicaragua and the local site selected for the implementation of the project. Section four details the information and communication system architecture, and section five covers the results obtained from the verification and validation phase. Finally, section six provides a discussion of the data, replicable conclusions, and an outline for future research projects.

2. Related Work Impact of ICT in Developing Countries

The UN declares that human development and technological advance can be mutually reinforced, creating a virtuous circle. ICTs allow the processing and storage of enormous amounts of information through communication networks. The importance of information management to achieve the MDG of eradicating extreme poverty and hunger is becoming more evident. Trueba (2006) concludes that the daily exchange of accurate information and institutional innovations required to encourage the participation of the population are essential issues for human development.

There is plenty of information in developing countries that can be used to identify and quantify the variables and characteristics of the environment to carry out interventions, sustainable programs, and projects in each target region. However, the information is not usually gathered in developing countries due to the lack of financial resources, unavailability of trained staff, and unaffordable communication systems.

Surana and colleagues (2008) described a project in rural India that used long-distance WiFi networking to enable high-quality videoconferencing between eye hospitals and remote village clinics, with the aim of eradicating blindness among the population. They conclude that WiFi technology reduces both deployment and operational costs since it does not incur frequency licensing fees and uses off-the-shelf hardware components. Additionally, unlicensed frequency gives the hospital the operational freedom to put up links whenever and wherever needed, improving the program's sustainability.

The report "The Opportunity of Mobile Technology for Healthcare in the Developing World" (Vital Wave Consulting, 2009) examines the potential of mobile communications to radically improve the delivery of health care services. Some benefits of mobile communications are better access to health care and health information, particularly among hard-to-reach populations; improved ability to diagnose and track diseases; more timely, actionable public health information; and expanded access to ongoing medical education and training for health workers. The report concludes that mobile health programs can have a significant and lasting positive impact on health outcomes such as reduced infant mortality, longer life spans, and decreased contraction of disease.

Mostafa et al. (2010) detail e-healthcare deployments among urban and rural populations in Bangladesh. The core of the proposed deployments is a generic e-healthcare unit that is amenable to different requirements in different deployment scenarios. They analyze the unique composition of each of these communities and the resulting requirements on an e-healthcare system focused on the patient side. The e-healthcare unit is a Healthcare Hut that includes telemedicine devices and uses the existing telecommunication link to bring e-healthcare to patients under various care scenarios.

The reviewed literature reveals different types of research based on ICTs to address problems in the health care sector in developing countries (Dezhi & Ganegoda, 2010; Kuriyan, 2008; Vatsalan et al., 2010). The benefits of ICTs include better health care for patients in isolated regions and for patients living in remote locations with inadequate medical services (remote monitoring of patients) and better availability of remote diagnostic and medical advice to deliver treatment for some diseases. Rural populations may benefit from ICT-based health care services by reducing the need to travel long distances to meet with a physician for a face-to-face consultation. In this regard, WiMAX provides extended coverage, and it is a much more cost-effective solution than wired technology in areas with lower population density, and especially in areas with poor communication infrastructure, such as San José de Cusmapa in Nicaragua. The WiMAX standard also provides *flexible architecture,* including point-to-point, point-to-multipoint, and ubiquitous coverage for distances under 50 kilometers. It is possible to make a *quick deployment,* one of the key issues to lower deployment costs in developing countries. In our case study, we use an unlicensed frequency (5.8 GHz) to avoid communication costs. This technology uses the Internet protocol that supports all multimedia services from voice over Internet protocol (VoIP) to high-speed Internet and video transmission (Ibikunle & John, 2008). WiMAX plays an important role in many projects and is used widely to support telemedicine and e-health solutions in developing countries (Chorbev, Mihajlov, & Jolevski, 2008; International Telecommunication Union, 2010; Ying Su & Soar, 2010).

3. Health System Profile in Nicaragua

Table 1 shows key data related to the health system in Nicaragua. According to the UN's Human Development Index (HDI, 2011), Nicaragua is included in the medium human development group of countries, ranked 129th with an HDI value of 0.589. This poor ranking is not justified if we check the macroeconomic values, although microeconomic data show that 15.8% of the population lives on less than $1.25 per day, and 3.3% of the population are

Table 1. Health System Profile in Nicaragua.

Indicator	Quantity
Human Development Index rank	129
Total population	5.9 million
Rural population % of total	42.4%
Maternal mortality ratio	1[a]
Total fertility rate	2.5[b]
Infant mortality rate	23[a]
Mortality rate for infants under age 5	26[a]

[a]Per 1,000 live births.
[b]Births per woman.

Internet users. Nearly half (42.4%) of the country's population is located in rural areas and suffers from inadequate health care facilities and a lack of medical practitioners; the maternal mortality rate is 1 death per 1,000 live births. The reasons for the unavailability of health facilities in rural areas are inadequate budget allocations to health, unequal distribution of income and productive assets, inaccessible areas, and the high probability of adverse natural phenomena throughout the territory.

3.1 Health Centers and Rural Health Posts

The Ministry of Health of Nicaragua (MINSA) is the country's main supplier of health services via a network of primary and secondary services (Pan American Health Organization, 2009). MINSA's first level of care consists of health care centers (HCs) and rural health posts (RHPs). MINSA operates health centers with different types of response capacity in each municipality—some for hospitalized patients and others for outpatients. RHPs have lower response capacity than HCs. Some rural health posts are staffed by the members of the community in those days in which health staff did not be able to attend the RHP. The RHP is located in small towns of fewer than 1,000 inhabitants that have no telephone lines and poor road networks. RHPs depend on the HCs for severe case referral, pharmaceutical deliveries, epidemiological management, and coordination of the general activities within the micronet. As a result of the widespread absence of communication systems, when health personnel need to exchange information, they have to travel on foot, on horseback, or by land vehicles, which may take hours or even days.

3.2 The Health Care Staff

The RHPs do not have permanent staff on site. They are staffed by the same health center professionals. Twice a week, the medical director of the HC makes priority visits to the rural communities in which there are rural health posts. Health professionals (typically a doctor and two or three nurses) travel to a rural health post to provide medical consultation about prenatal care for pregnant women, child growth and development, and immunization. As a consequence, the HCs are partially unattended during certain times when the health care professionals are attending other patients in the area. The health care staff is also responsible for the administrative tasks because of the lack of personnel.

In general, people do not have technical skills (especially in ICTs), and this is certainly the case of the target communities of the proposed project in the Cusmapa region of Nicaragua.

3.3 Administrative and Health Information Systems

Information updates are manually performed and are based on paper reports. Periodically, the HC submits to SILAIS (the comprehensive local health system at the regional level) epidemiological surveys and reports on the monitoring, promotion, growth, and development of children; medical visits during the month; number of births; postpartum maternal home income; and family planning.

3.4 Demographic Situation and Resources

The vast majority (80%) of the population in the Cusmapa region is devoted to rural activities, and most of the roads must be traveled on foot or by beast. The report of the Pan American Health Organization on health inequalities in Nicaragua shows that the percentage of the population living more than 5 kilometers from the nearest health center is much higher in rural areas, taking about 81 minutes to reach by car or 6 hours on foot. The existing human, financial and material resources are insufficient for delivering an adequate and timely health service. Given the above background, we have identified the following needs in rural communities (RHPs) and within the municipality (HCs).

Rural Communities

The rural communities in Cusmapa have the following problems:

- No electrical power
- Huge distances between rural communities and the health care center
- No road infrastructure
- No updated information on the health and nutrition status in the area
- No public communication infrastructure (some people have mobile phones but often cannot use them because of lack of credit to make calls)
- No health posts in some communities
- Insufficient health staff (although some physicians hold consultations in some areas twice a week, there are not enough health care practitioners to provide adequate care to all the communities)
- No training in ICTs

Municipality

The municipality has the following problems:

- The resources available in the health center depend on the budget allocated by the Ministry of Health, and sometimes it is not enough to provide health services to all the communities.
- The communication infrastructure is only used by the medical doctor, and the budget allocated by SILAIS in most cases is not enough.
- The medical and administrative staff are insufficient to serve the entire community, taking into account the segregation of the population and the difficult access to the remote rural areas.
- There is little training in ICTs.

3.5 Profile of the Site Selected for the Implementation of the Project

The initial feasibility studies about impact on the MDGs conditioned the decision to choose the municipality of San José de Cusmapa to deploy the pilot in a scalable and replicable way. The decision was made based on the huge problems of accessibility due to the extremely steep terrain and the high levels of chronic malnutrition (about 32.5%). San José de Cusmapa is a municipality in the Madriz department of Nicaragua. It is located 274 kilometers from the capital, Managua, and it contains three urban areas and seven microregions comprising 26 communities. The population is predominantly rural (80.1%; INIDE, 2005), and because access is very difficult, the area is quite isolated from the rest of the country. The telecommunication infrastructure is limited in San José de Cusmapa, where the HC is located, and there is no telecommunications infrastructure in El Carrizo, the community with the RHP that is located about 12 kilometers away by foot.

The San José de Cusmapa HC is the only facility attending a rural population of 7,072 inhabitants. The HC is headed by a medical doctor supported by one family doctor, six nurses, and a health care technician. It has one ambulance to transport patients. The Cusmapa HC depends on the health care area whose head is located in Somoto, almost two hours away by car.

We selected an RHP located in the El Carrizo community, which is 7.4 kilometers in line of sight from the nearest health center. Access to this rural health post is difficult. The area lacks a single asphalted road and has extremely steep terrain and altitudes of 800 to 1,300 meters above sea level (Figure 1). The RHP is quite deteriorated, has few medical supplies, and provides uneven care. The RHP covers almost 2,000 people in the seven surrounding communities (Las Jaguas, Jocomico, El Gavilán, El Ángel III, El Jobo, Aguas Calientes, and la Jabonera). The area is in need of a timely health care delivery solution. There is a 58.33% rate of chronic severe malnutrition and a 26.88% rate of stunting.

4. Information and Communication System Architecture

The ITU report titled "Implementing e-Health in Developing Countries. Draft" requests entities to be

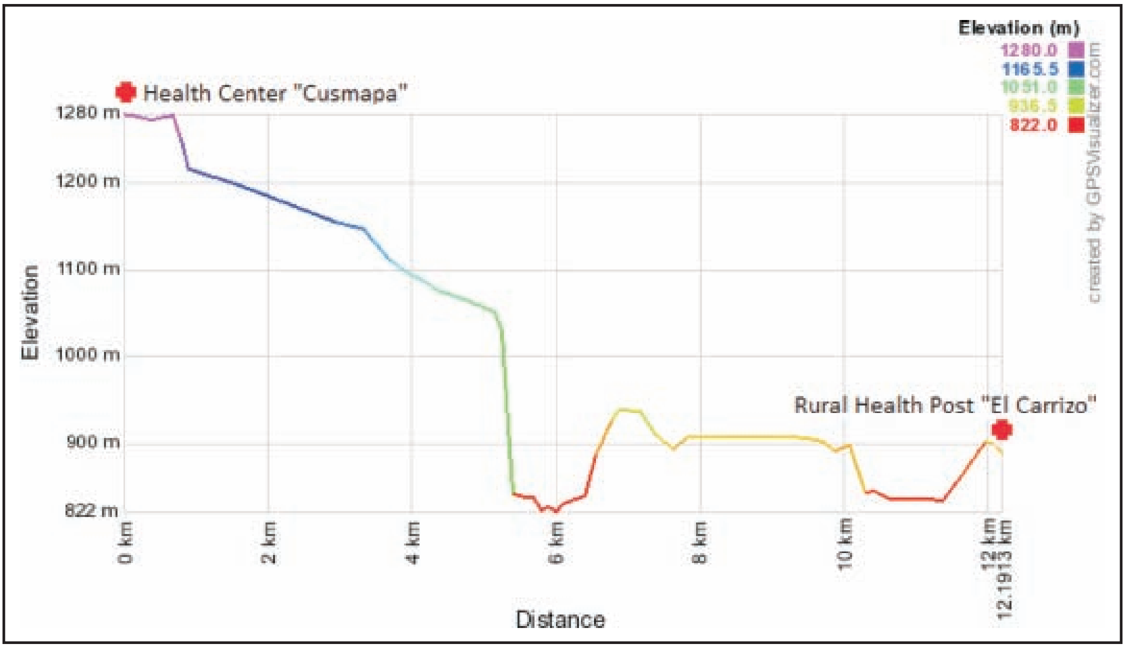

Figure 1. Profile of the geographical environment.

respectful with existing organizational teams in places where technology is deployed (ITU, 2008). The report recommends that local people take control of the technology (local empowerment) to evolve it and promote innovation in their own processes. In line with these recommendations, the main objective of this research is to improve health care access for maternal-child populations through sustainable, low-cost, replicable, and scalable ICTs. This main objective is structured through two specific objectives:

- **Specific Objective 1.** To develop a communication platform for ICT-based services from the health center of San José de Cusmapa to remote communities such as El Carrizo. The communication platform should include a voice service between communities and with the medical staff of the municipality located at the health center. The platform must be compatible with existing organizational procedures in the area and address the limitations outlined below.
- **Specific Objective 2.** To deploy a support information system for the current maternal and child health service. The system will include an information platform that will improve early prenatal check-ups and the growth and development monitoring of children. More accurate monitoring of maternal and child health can lead to early detection of malnutrition.

4.1 General Principles of the Model

After defining the objectives, performing background analysis, and obtaining the functional and nonfunctional requirements, a general model of the system has been defined. This model must represent the different functional parts that make up the complete solution, taking into account the current organizational system and the possibility of replicating the system in other communities. Some of the key characteristics considered at the design and deployment phase are shown in Table 2.

4.2 Communication Platform

According to the design principles shown in Table 2, we propose a network infrastructure consisting of 1) WiMAX-based point-to-multipoint backbone links to interconnect transmitter hybrid stations (deployed on the HC) and subscriber hybrid stations (deployed on the RHP or communities) and 2) a WiFi-based point-to-multipoint WLAN access link that provides access to wireless user devices (laptops, WiFi-enabled mobile phones, etc.) placed at both loca-

Table 2. Design Principles.

Characteristic	Description
Technology maturity	WiMAX and WiFi are the most influential technologies today. WiMAX can be considered a solution to fill holes in branch-tree WiFi hot spots coverage and to enable wireless connectivity over long distances. WiFi technology is mostly used in laptops, mobile phones, cellular phones, and smartphones. Therefore, the components to deploy networks based on this kind of technology are readily available and cheap, which lowers maintenance costs.
Low cost	WiMAX requires little or no external plant construction. In rural areas, the long distances from the core network access point and the scattered location of households and communities make any deployment very costly. WiFi enables devices such as laptops and cellular devices without any communication cost.
Flexibility	The Internet protocol (IPv4) used in the network allows an appropriate integration of services since it is included in current ICT developments and communication terminals. The proliferation of devices that accommodate wireless protocols offers tremendous flexibility in the design of applications for rural areas.
Aggregated services	Our solution should not be restricted to providing only a communication link; it should provide strong connectivity between urban and rural communities within an area and therefore enable aggregate future applications such as remote data collection, remote monitoring, epidemic outbreak tracking, communication, and training for health care workers.
Baseline	This project could allow donors or stakeholders to deploy the system in other communities, scale the solution, and develop a revenue model for the benefit of the population.

tions. This solution adds innovation to previous radio point-to-point experiences in the area because users can use WiFi-enabled mobile phones instead of fixed radios without any cost for distances over 10 kilometers. Figure 2 shows the connection links.

Hybrid Base Station: This long-distance point-to-multipoint link (from 1 to 30 kilometers) for wireless broadband outdoor connectivity in the HC includes a small internal drive, an external drive mounted on a 30-meter mast, and a 120-degree sector antenna for 5.8 GHz (15 dBi) on a license-exempt band in order to cover all the target communities in the area. Stable connectivity is provided between the health care center in the municipality and rural communities through a node mounted on an available old radio tower at the HC.

Hybrid Subscriber Unit: This component enables data connection to the hybrid base station and supports multiple users at the RHPs. The subscriber unit includes a vertically polarized high-gain flat antenna integrated and Wi^2 outdoor with two 8-dBi omnidirectional antennas. The use of packet switching technology provides users with always-on connection to the network, enabling immediate access to services. This setup provides an efficient platform for intranet services such as VoIP connectivity between the HC in the municipality and the surrounding communities. These devices are placed in communities, such as our pilot community El Carrizo, where no electrical network is available. Some solar panels at a local school in El Carrizo were used to supply enough power (about 30 watts) to sustain all the devices of the subscriber unit.

Point-to-multipoint WLAN Access Links: We expand the existing capabilities of WiMAX network by using a Wi^2 extender with two 8-dBi omnidirectional vertical antennas at the HC. This component enables WiFi capabilities to connect different devices such as laptops and mobile phones.

Wireless User Devices: WiFi-enabled client devices such as laptops, softphones, or cellular phones are used to support VoIP communications. Nokia E51 and E65 phones were validated at the El Carrizo rural post.

The same scheme can be replicated in other communities. It is necessary to have appropriate terminals that support the integration with the platform and the functions required for services that are

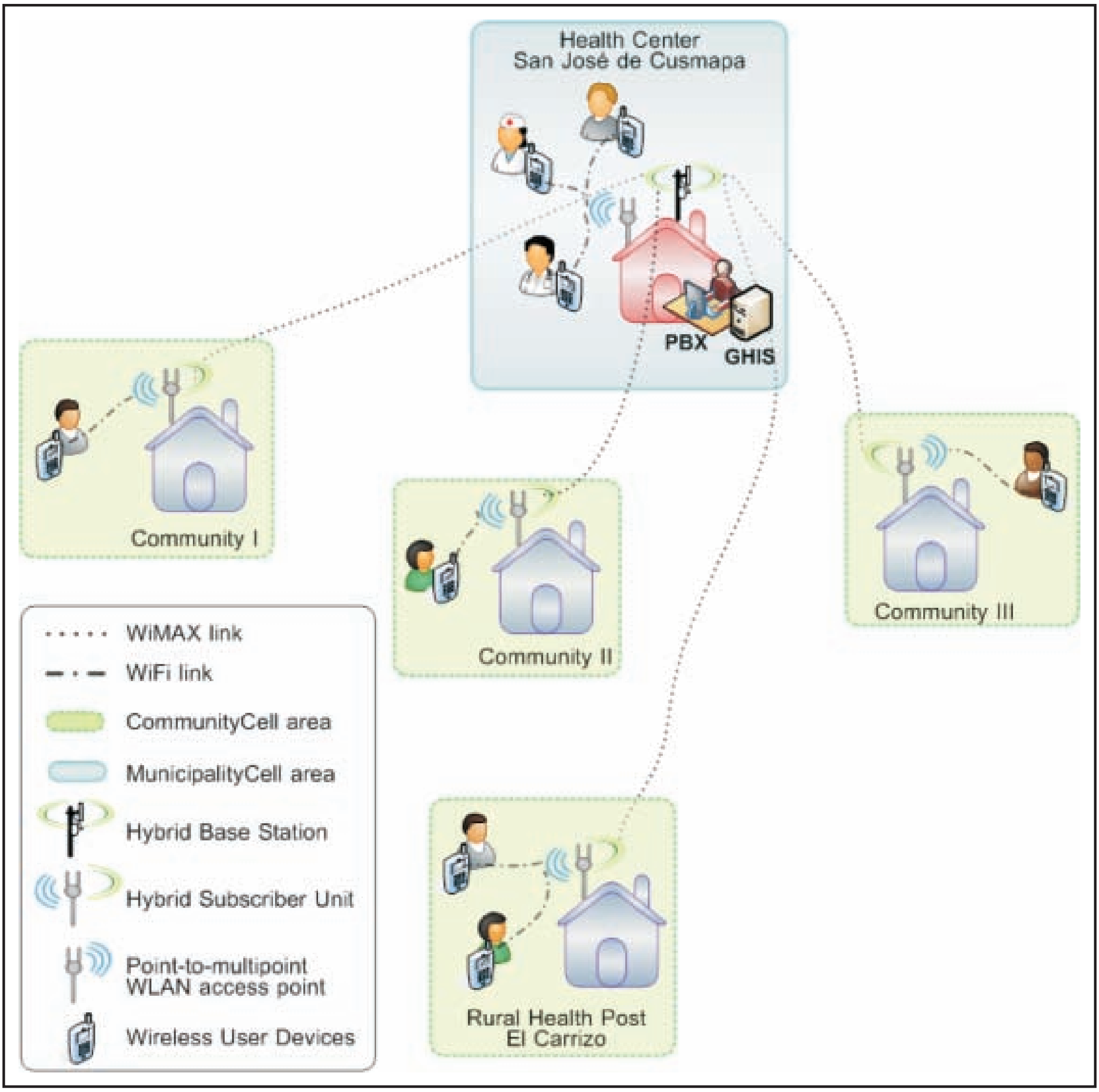

Figure 2. Architecture components.

deployed in both the HC and RHP. They must also fulfill the economic and energy issues obtained from the characterization of the location.

The voice support defined in the objective has been implemented using VoIP. Mobile telephones based both on SIP protocol and wireless have been supplied to the physician, nurse, and technician in the San José de Cusmapa HC, and softphones have been installed on computers. The same kinds of phones have been supplied to the El Carrizo RHP (midwives, brigade). A communications server that includes software that makes the PBX functions, is provided to make calls. Hence, we provide a system WiMAX-WiFi network with VoIP PBX that allows free local communication between health centers and communities at distances of up to 30 kilometers using low-cost mobile phones.

4.3 Information System to Support Maternal-Child Health

A geographical health information system (GHIS) was developed to facilitate the representation of the health and nutrition indicators in communities and

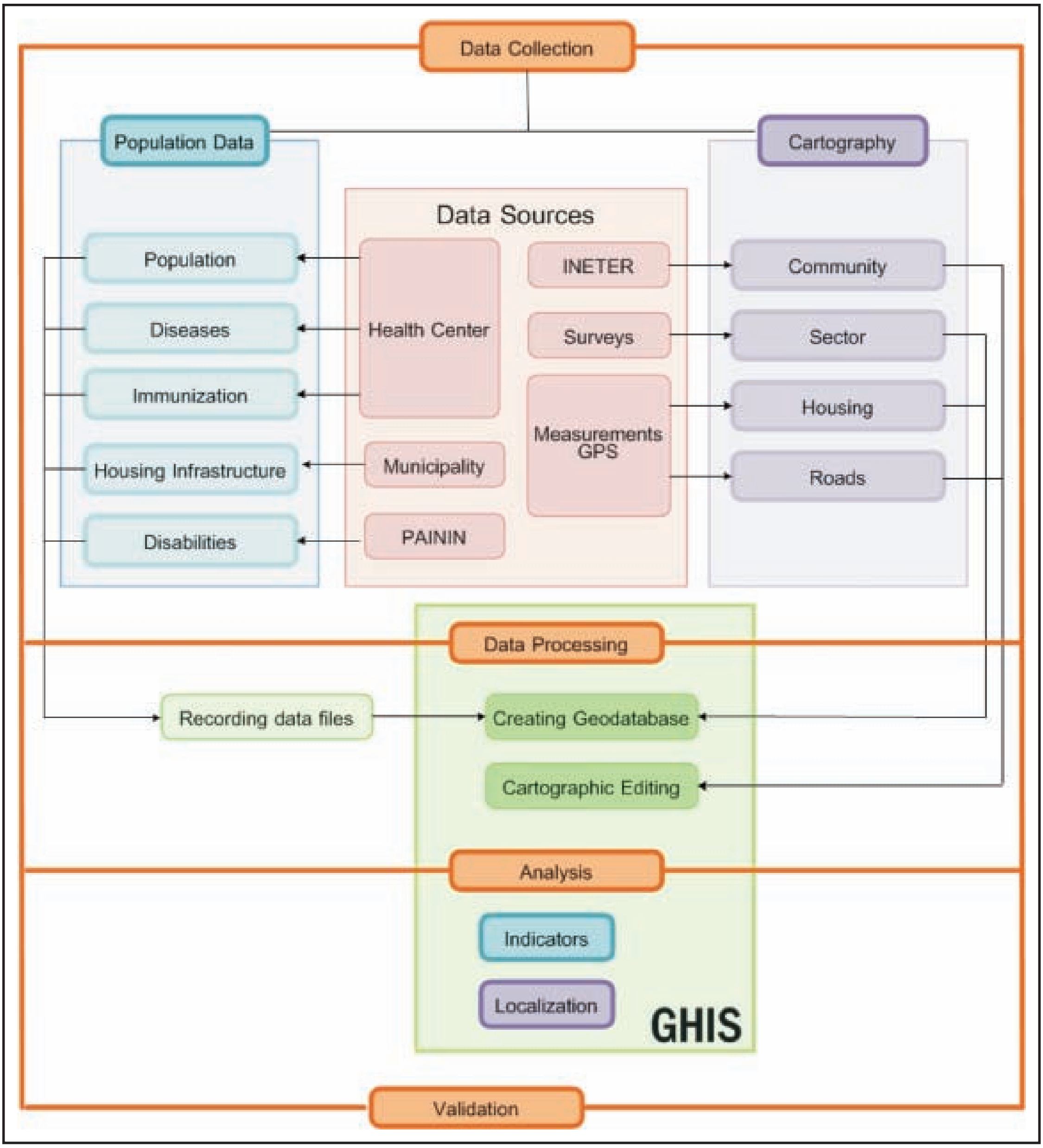

Figure 3. Phases of the development and implementation of the geographical health information system.

sectors. This application combines geographic information systems with health data of the population to analyze the distribution of the maternal-child population at risk, the distribution of diseases, and the distribution of people with disabilities.

Figure 3 shows the different stages of development and implementation of the GHIS. The first phase deals with data collection such as nutritional status, immunization, disabilities, diseases, housing infrastructure, and geographical coordinates from the pilot communities. Data were collected during a six-month period by surveying the population at local communities. We used the forms from the Integral Attention of Nicaraguan Children Program of the Ministry of Family, the Nicaraguan Program of Ministry of Family's Integral Attention to Children

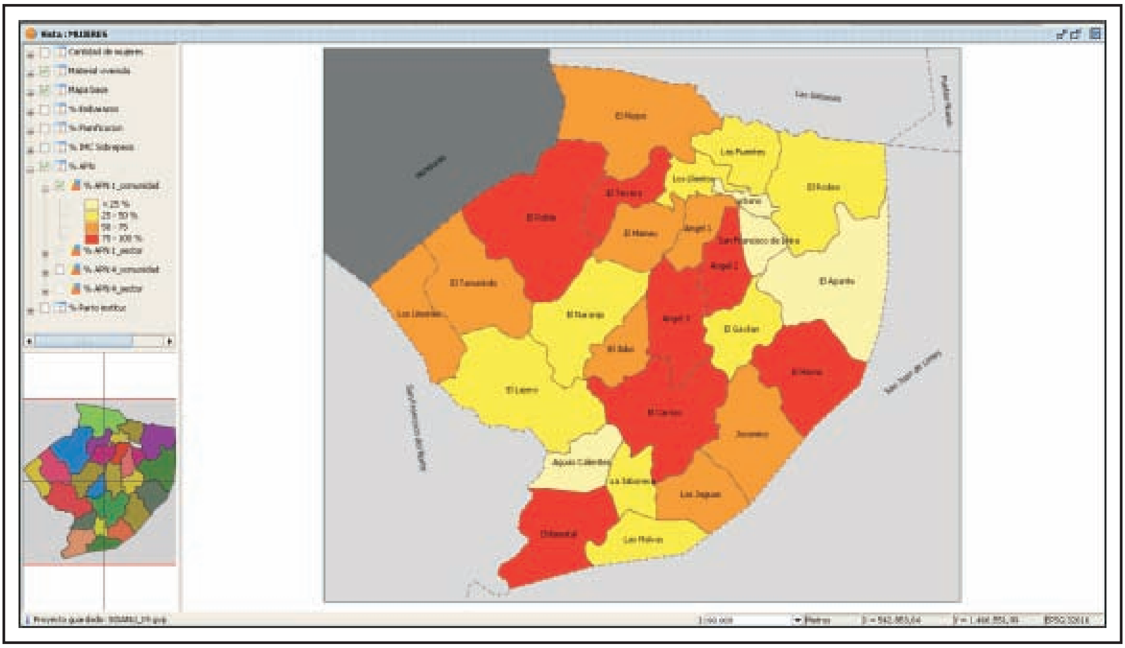

Figure 4. Communities of San José de Cusmapa.

and family histories provided by the health center. Some health indicators of each module are shown in Table 3. The cartography information was provided by the Nicaraguan Institute of Territorial Studies. The second phase focused on data processing to transform the acquired paper data to digital files to process and manage the database. This phase was performed with GvSIG free software. Finally, the validation phase was carried out with local participants such as the health center's medical staff.

As shown in Figure 4, San José de Cusmapa is a territory comprising seven micro-regions and 26 communities. Due to the high levels of chronic malnutrition in the region, it is important to monitor the maternal-child health status of the population. To accomplish this, we categorized four modules for monitoring: fertile women, children, people with disabilities, and people with diseases. This information is depicted in three levels: communities, sectors, and housings.

The indicators that characterize poverty at the community level appear in Figure 5. The number of childbirths with medical assistance is related to poverty because the low-income population has the least access to key health services such as institutional childbirth. Because of this, the population does not have enough economical resources to pay the direct and indirect cost of the health care; additionally, they live in dispersed and remote rural areas. This aspect makes it especially hard for people living under these conditions to access health care services.

Figure 6 shows disease prevalence among smaller areas of the community to facilitate the detection of outbreaks and assessment of isolation (by distance, number of population, or by lack of health care).

Additionally the Figure 7 shows disease prevalence at housing level. We use geographical coordinates to locate patients' houses and to analyze possible relationships between health status and characteristics of the house (such as roofing, floor, and wall materials, access to potable water, sewage tanks, and garbage). This information allows for timely and accurate detection of the source of a problem in order to implement measures to alleviate and permanently improve the health status of the population.

The geographical health information system also allows the representation of issues related to maternal-child health and nutrition through thematic mapping. It is possible to obtain reports such as those patients who need follow-up appointments for prenatal, nutrition, and immunization care. The objective of perinatal surveillance is to reduce maternal and perinatal mortality.

Our system provides information that allows the

Table 3. Baseline Indicators for the Geographical Health Information System.

Module	Health Indicators
1. Fertile Women	1.1. Women between 15 and 49 years.
	1.2. Number of women with at least one prenatal control.
	1.3. Number of women with four prenatal controls.
	1.4. Percentage of women with anemia.
	1.5. Number of women using family planning (age of risk under 19 and over 35).
	1.6. Percentage of women who are pregnant.
	1.7. Percentage of women with obesity or underweight.
	1.8. Number of fetal deaths.
	1.9. Number of maternal deaths.
	1.10. Number of maternal deaths in pregnancy.
	1.11. Number of maternal deaths in childbirth.
	1.12. Number of maternal deaths in puerperium.
2. Infant	2.1. Number of infants between 0 and 5 years.
	2.2. Percentage of childbirths with medical assistance.
	2.3. Percentage of infants with low birthweight.
	2.4. Percentage of immunized children against BCG, MMR under 1 year.
	2.5. Percentage of immunized children over 6 months against IPV, OPV.
	2.6. Percentage of immunized children over 1 year against DPT.
	2.7 Prevalence of malnutrition underweight for children under 5 years.
	2.8. Prevalence of stunting malnutrition of children under age 5 years.
	2.9. Prevalence of malnutrition as low weight-for-height of children under age 5 years.
	2.10. Percentage of infants under 5 years with unsatisfactory psychomotor ability.
	2.11. Percentage of children under 5 years malnourished.
	2.12. Percentage of infants exclusively breast-fed until 6 months of age.
	2.13. Prevalence of children under age 5 years with anemia.
	2.14. Prevalence of infants under age 5 years with ARI.
3. People with disabilities	3.1. Number of people with disability.
	3.2. Number of people by type of disability (according to International Classification of Functioning, Disability and Health).
	3.3. Number of people with change in mental functioning.
	3.4. Number of people with sensory changes and pain.
	3.5. Number of people with change in the operation of voice and speech.
	3.6. Number of people with changes in organ function.
	3.7. Number of people with neuromusculoskeletal and movement disorders.
	3.8. Number of people with changes in the structure and function of skin.
4. Diseases	4.1. Number of people by type of disease according to the risk map of the HC (ARI, TB, ADO, chagas, leptospirosis, HIV, classical dengue, severe dengue, malaria).

monitoring of children's growth and development. The system updates the information about the children's nutrition, then it allows it to schedule the next appointment. As a result, we can collect a large amount of data that can be used to generate strategic information, such as the number of children under age 5 grouped by community or sector, the number of children classified as malnourished, and so on.

The local health staff can easily identify various

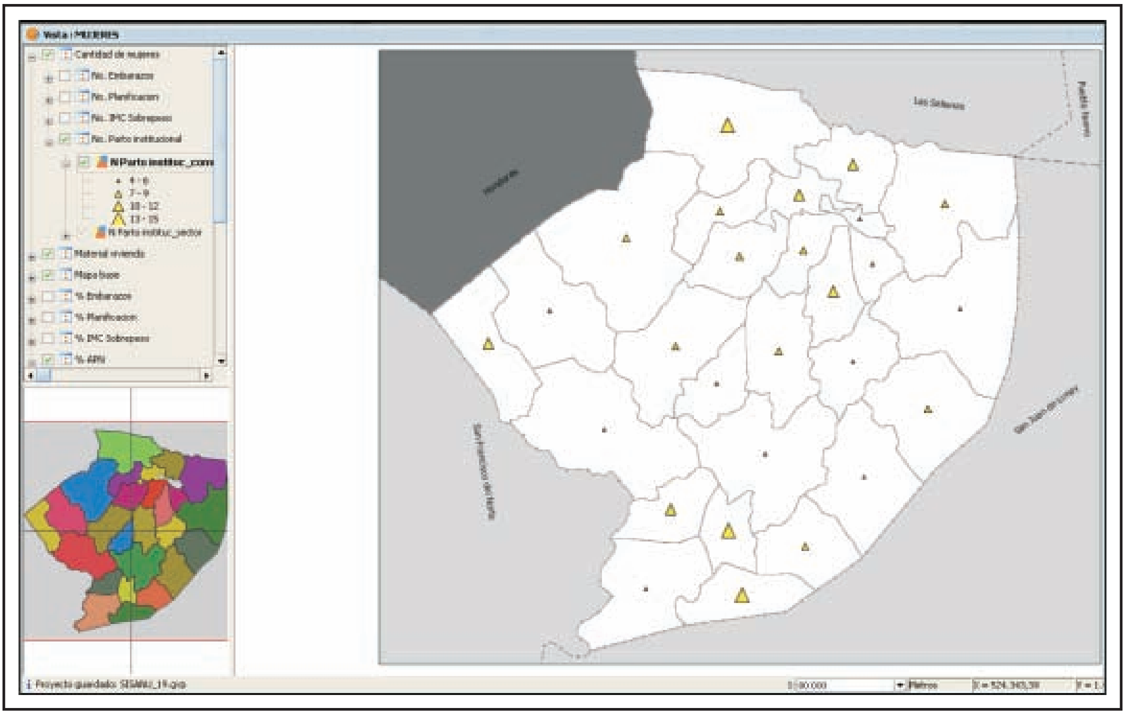

Figure 5. Number of childbirths with medical assistance by community.

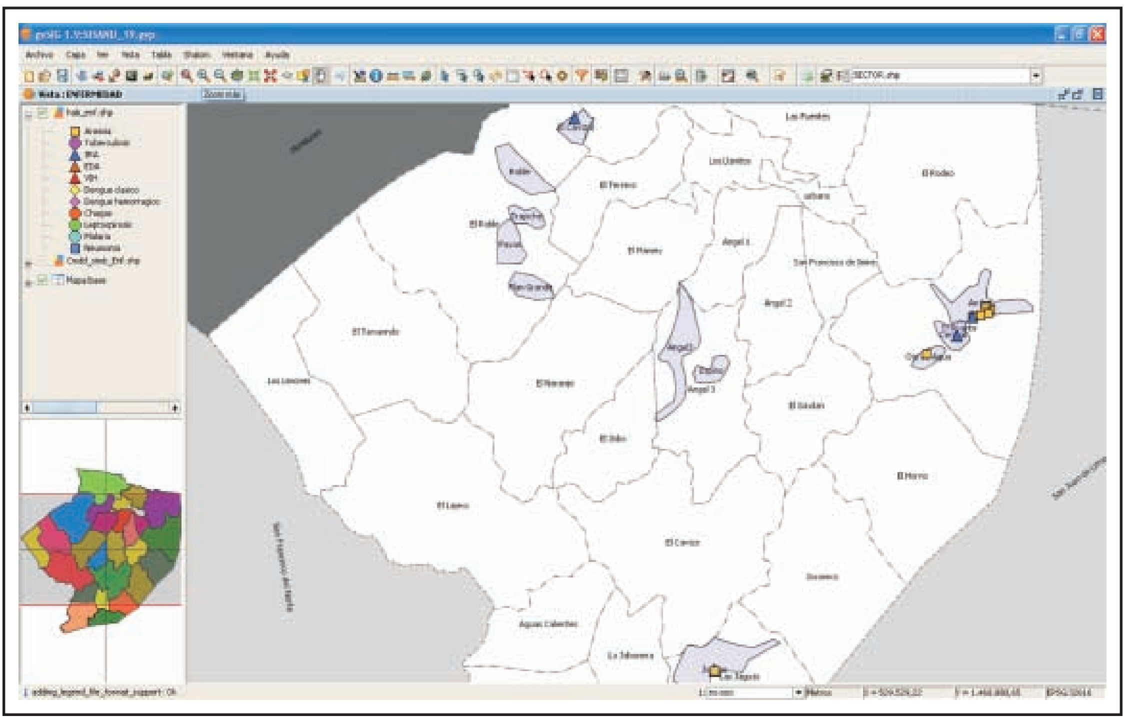

Figure 6. Types of disease by sector.

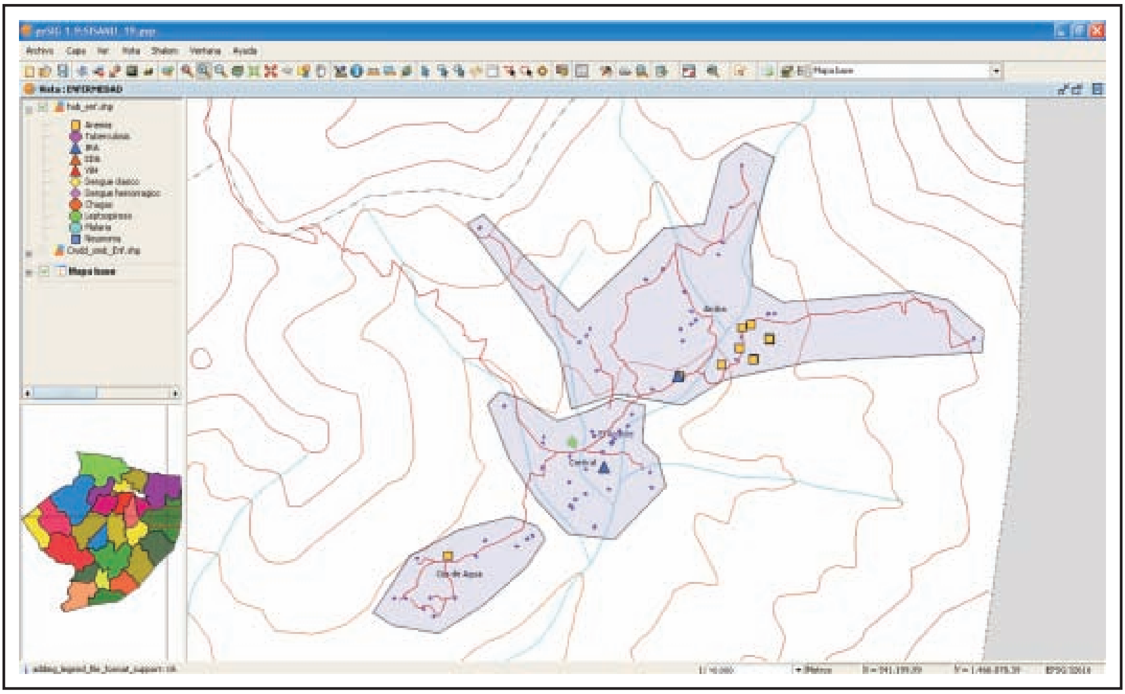

Figure 7. Type of disease by housing level.

health phenomena by using the GHIS since they can study the main risk factors for a specified period and location. Additionally, the GHIS can help to identify patterns in a spatial distribution of risk factors and their impacts on health.

5. Validation and Results

A trial period of 12 months was defined between August 2010 and 2011. The head of the Cusmapa HC, a health care technician, and six nurses were involved in the pilot. During this validation period, system information was obtained via two procedures: intermittent stays in the region of San José de Cusmapa by a member of the research group and ongoing e-mail communication with the health care professionals at the HC. The validation results for the proposed solution are outlined below.

5.2 Technical Verification

5.1.1 Wireless Links

Both WiMAX and WiFi links have been running continuously except for short periods of power outages due to supply failures. Before the final deployment, the resulting technology (Alvarion BreezeNETB and Wi2 Extenders) was verified in the laboratory of R&D EUIT of Telecommunication at the Technical University of Madrid to test the solution performance. As shown in Figure 8, simulations were done with Radio Mobile free software by using real data gathered during the analysis stages.

According to a Tx power of 0.0079W, 9 dBm, and taking into account a line loss of 0.5 dB, we needed a radiation power of 0.89 W having an antenna gain of 21 dBi. The position of the HC and communities suggested an antenna mast of 32 meters. VoIP transmission did not require broadband links, although the full WiMAX and WiFi links ensured 1 Mbp for the 7.4-kilometer distance. Because the school in El Carrizo is at a higher elevation, we only needed a 6-meter mast to provide the antenna height of 12 meters suggested by the Radio Mobile simulation.

The final installation and training activities (which took place over one week) validated the laboratory tests. Despite the drawback of severe weather because of the rainy season in the area, about 70% of the radio signal power was achieved according to the transmitter link indicator, which allowed satisfactory VoIP communication.

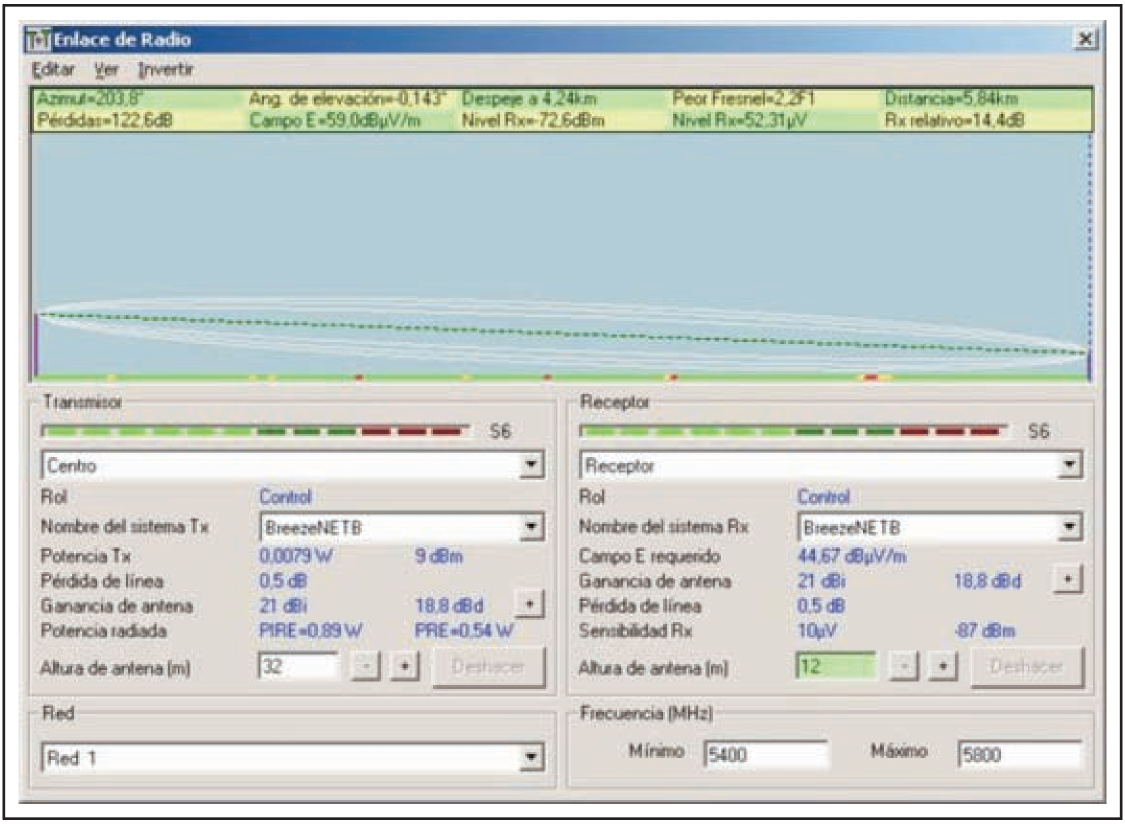

Figure 8. WiMAX link technical verification.

Figure 9 shows the installation of the mast and the WiMAX-WiFi antennae and the training activities at the El Carrizo school.

5.1.2 IP Protocol and Voice Service: PBX

Communication difficulties arose because of the configuration of mobile terminals located in El Carrizo. This incident created intermittent interruptions in voice service that cannot be solved without technically trained personnel.

No problems were detected in VoIP performance over the radio links. Occasional reboots did not cause any error in the PBX configuration, and there was no need to manage the radio links. The 3CX free version software employed is very user-friendly and facilitates relatively complex tasks such as adding a new terminal and the assignment of an extension.

5.2 Organizational Assessment

Municipality of San José de Cusmapa

During the last year, the head of the HC at San José de Cusmapa changed, because the position rotates every two or three years. These personnel changes led to changes in the staff organization and especially in the allocation of roles. This organizational change led to discontinued use of the GHIS and additional complexity involved in recording or updating new data for year 2011. Although the degree of satisfaction of the medical team seems appropriate, they are requesting new features to be added to update the user interface. This request was considered in the review tasks performed in August 2011 by installing ANTHRO software provided by the World Health Organization. Training and validation activities were done with the health care technician in charge of the HC. Based on the data collection, we are also developing a simple Web-based user interface for the forms used by medical staff for data collection.

Rural Community El Carrizo

The RHP mobile devices at El Carrizo are managed by local volunteers and supported by the local communities to help with organizational aspects. However, due to their partial dedication, the technology

Figure 9. WiMAX-WiFi training and installation.

has not been always available. The review tasks led to the establishment of a new weekly communication protocol to enhance continuous availability and maintenance of the mobile devices. The validation of this new measure is being tackled on an ongoing basis.

6. Discussion, Conclusions, and Future Research

Once the technical complexity is solved, the main challenges to incorporating the system in the HC's and RHP's daily routine are organizational. The acquired knowledge allowed the design of the first stage of the system and provided a lot of feedback for potential problems to be solved in later stages. In this sense, the support provided by the local population (at the health center, in the rural communities, and in the municipality) was crucial to put the system into place. Regional support from Universidad Nacional Agraria at Managua is crucial for solving technical maintenance problems going forward.

Regarding the technology to support the solution in developing countries, three technologies can be useful to replicate this solution: WiFi for long distances, a WiMAX-WiFi hybrid, and handheld digital transceivers at 466 MHz. The decision about which is the best option should rely mainly on three factors: the organizational maturity of the rural area, the topology, and the initial investment budget.

A high turnover among the health staff is a risk for the technology implementation. To reduce this risk, we propose institutionalizing the system by creating and implementing a protocol. The technology will be set up as a basic component that will support the daily activities related to reporting information to the regional health office. We found it extremely valuable to optimize the work flow to ensure that the solution will be used by health staff as part of their daily activities.

Although knowledge and technology transfer was done with the health technicians at Cusmapa, it is important to involve other health workers at the regional health office (SILAIS) to prevent future staff modification. This process needs to be carried out once the initial pilot reaches a certain level of maturity. Both bottom-up and top-down strategies are needed to completely deploy the system in a sustainable way. A bottom-up strategy with a mature pilot supports communities by involving the rural health workers. A top-down strategy involves regional health authorities in adopting the system and provides the policies and resources needed to implement and encourage its use. In this way, the service reaches a high maturity level, which is crucial for producing an adequate knowledge and technology transfer to technicians, health workers, and regional participants.

6.1 Lessons Learned

Several lessons from this research project can be applied to future research and decisions pertaining to the development and deployment of e-health solutions in developing countries.

- *Power problems:* Unfavorable weather conditions in Cusmapa made it necessary during installation to attach a lightning rod to the top of the tower and a basic grounding system. Despite this precaution, during the first year after the deployment, some network devices were damaged because of lightning. The damage was caused by induction hits, and it was necessary to install gas tube arrestors at both ends of the cable. Induction hits are caused when lightning strikes near the tower, and this experience suggests that these arrestors need to be grounded directly to the ground wire installed on the tower if it is at the high end (Flickenger, 2008). The bottom end needs to be grounded to something electrically safe, such as a ground plate or a copper pie that is consistently full of water.

- *Fault network management:* Network faults occurred during the first year of the deployment because of power failures. The local staff lacked the expertise to reconfigure the mobile phones and repair some faults of the network devices. Technically trained personnel were needed to resolve these problems. Therefore, we recommend developing a simple auto-configuration and management tool to improve the operational self-sufficiency of the network.
- *High staff turnover:* Although a change of medical director is usual in these regions, it caused problems with the transfer of the solution installed, and even the user manuals became obsolete. To minimize the impact of staff turnover on the management of the system, we reached an agreement with the external cooperation department of the National Agrarian University, which will provide ongoing technical assistance in San José de Cusmapa.

The system has been designed to be replicable and scalable. As confirmed by Universidad Nacional Agraria and SILAIS, the system could be replicated in other regions and, most importantly, in underserved rural areas. We have used this experience to develop a similar program in Jocotán, Guatemala, which is planned to be replicated in 2012, avoiding the problems previously mentioned. Future ongoing research has three main action lines:

- Evaluation of the global solution in other locations. Two more communities of Cusmapa are addressed (El Roble and El Apante). Furthermore, La Mina, a community located more than 10 kilometers from Jocotán municipality, is also targeted in Guatemala.
- Addition of new functionalities to the system. In addition to a compatible telemonitoring module for the information system described in this article, a low-cost mobile-based system has been validated in the lab to locally gather data about the height and weight of the children in the area to be transmitted remotely to the information server. The measurement, recording, and interpretation are essential to identify malnutrition problems, which are critical problems among the child population in this region.
- Finally, to support telematics services such as epidemiological tele-surveillance, the communication platform must be extended. These types of services are crucial for improving the health of the community and for involving cooperation among other groups in supporting the system. ■

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